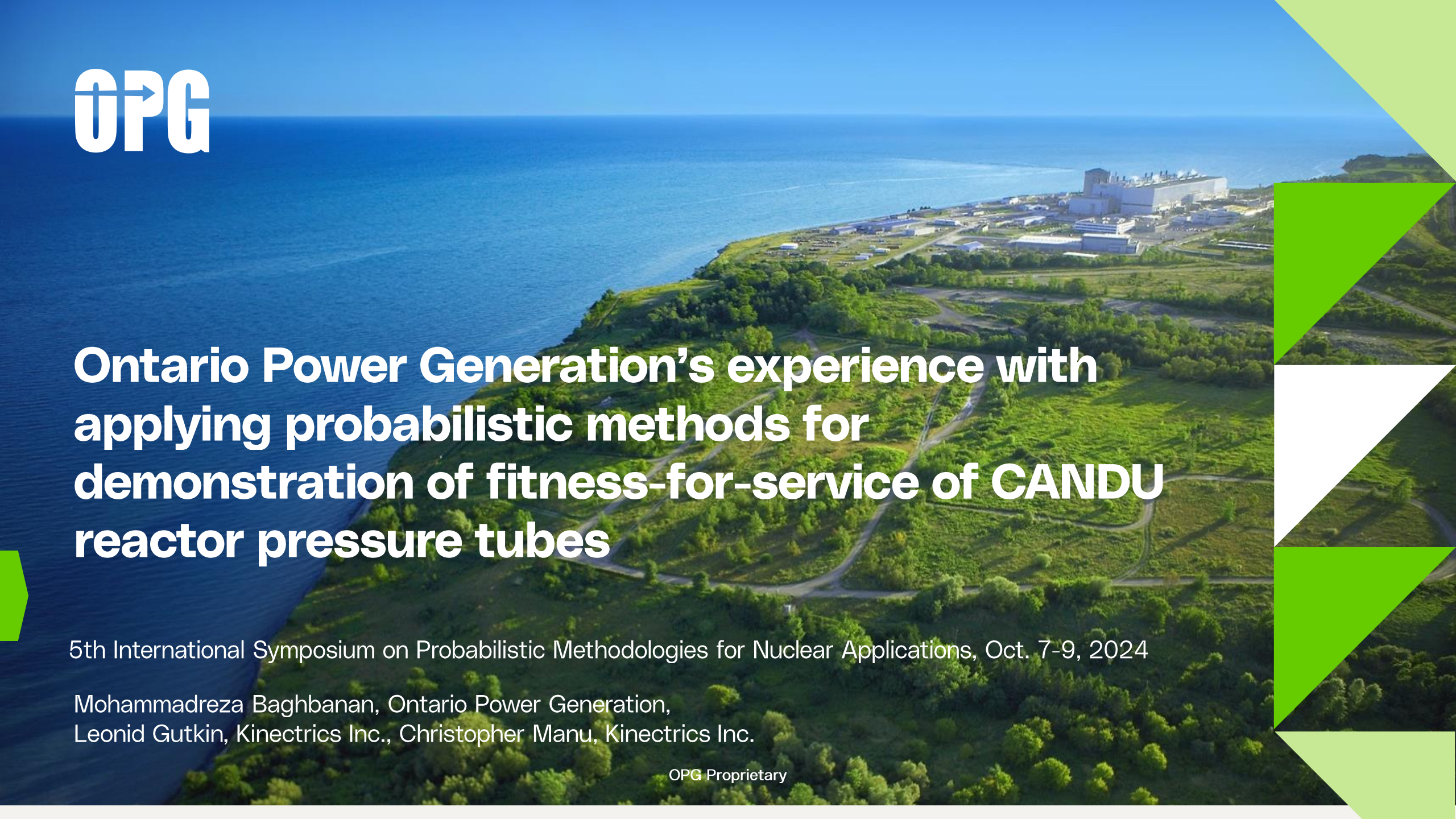

Ontario Power Generation's experience with applying probabilistic methods for demonstration of fitness-for-service of CANDU reactor pressure tubes

5th International Symposium on Probabilistic Methodologies for Nuclear Applications, Oct. 7-9, 2024

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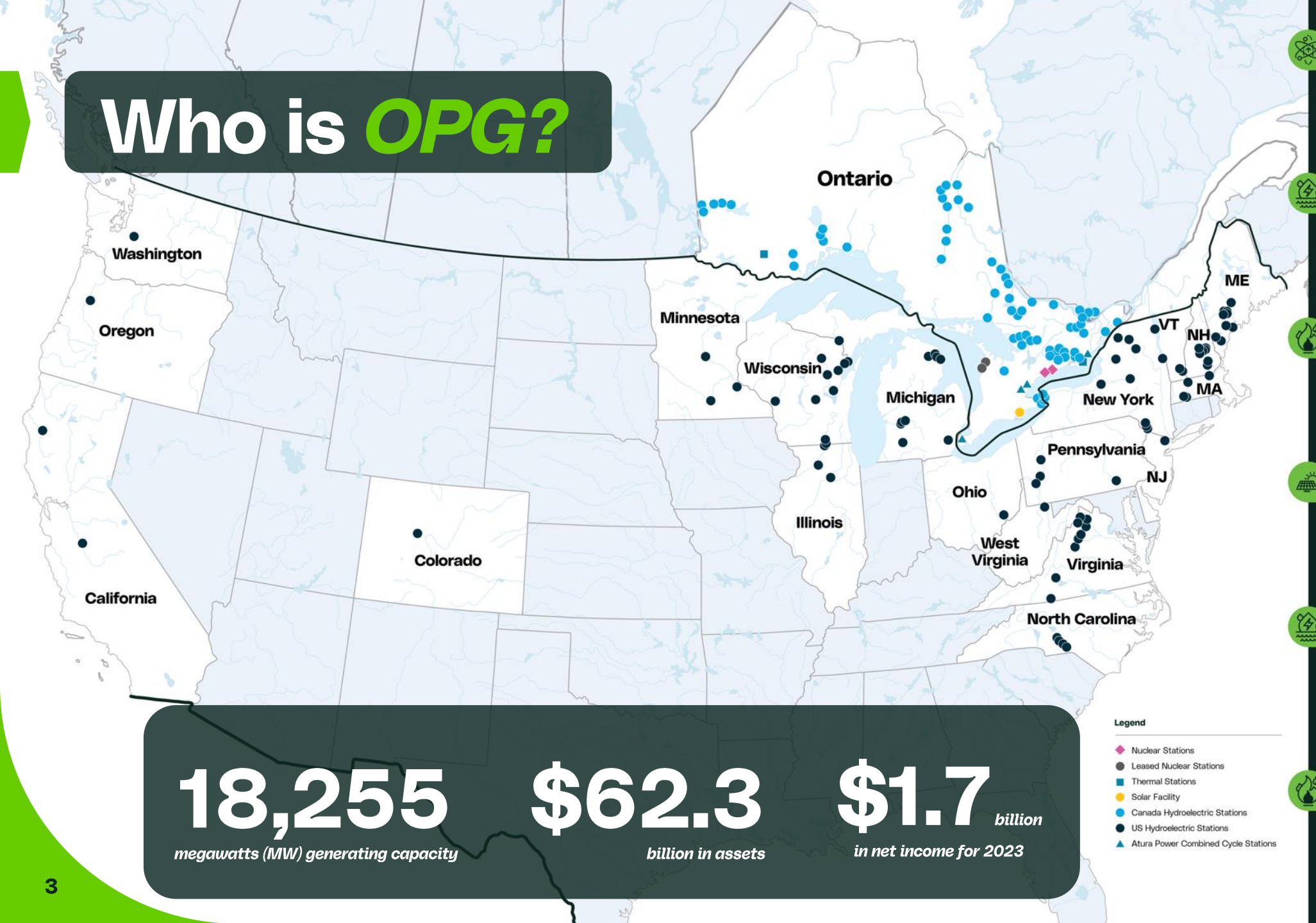
Leonid Gutkin, Kinectrics Inc., Christopher Manu, Kinectrics Inc.

Outline

- Who is OPG?
- Life cycle of the CANDU nuclear reactor
- Fitness-for-service (FFS) evaluations for CANDU pressure tubes
  - CSA N285.8
- Probabilistic evaluations of pressure tube fitness-for-service
  - History of development and application
  - Uncertainty analysis

Who is *OPG?*



18,255
megawatts (MW) generating capacity

$62.3
billion in assets

$1.7 *billion*
in net income for 2023

2
Nuclear Generating Stations

66
Hydroelectric Generating Stations in Canada

2
Thermal Stations

1
Solar Facility

85
Hydroelectric Generating Stations in the U.S.

4
Atura Power Combined-Cycle Generating Stations

Who is *OPG?*

Ontario

Washington

Oregon

California

Colorado

Minnesota

Wisconsin

Michigan

Illinois

Ohio

West Virginia

Virginia

North Carolina

Pennsylvania

New York

NJ

MA

VT

NH

ME

18,255 *megawatts (MW) generating capacity*

$62.3 *billion in assets*

$1.7 *billion in net income for 2023*

Legend

- Nuclear Stations
- Leased Nuclear Stations
- Thermal Stations
- Solar Facility
- Canada Hydroelectric Stations
- US Hydroelectric Stations
- Atura Power Combined Cycle Stations

2
Nuclear Generating Stations

66
Hydroelectric Generating Stations in Canada

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Hydroelectric Generating Stations in the U.S.

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OPG

Climate Change Plan

"Our promise is to be *a catalyst for efficient, economy-wide decarbonization.*"

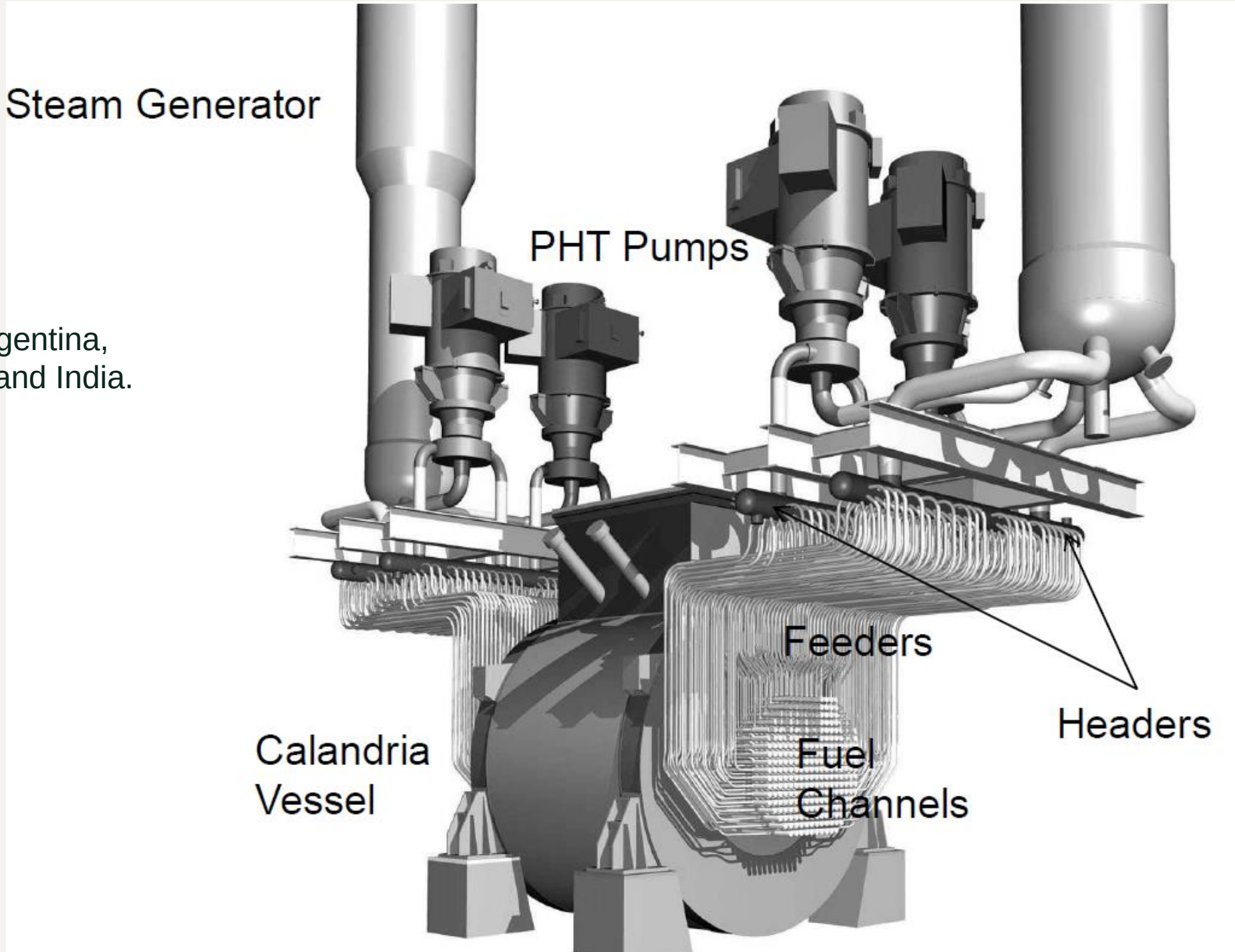
Ken Hartwick
President and CEO, OPG

A net-zero carbon *company* by **2040**

A net-zero carbon *economy* by **2050**

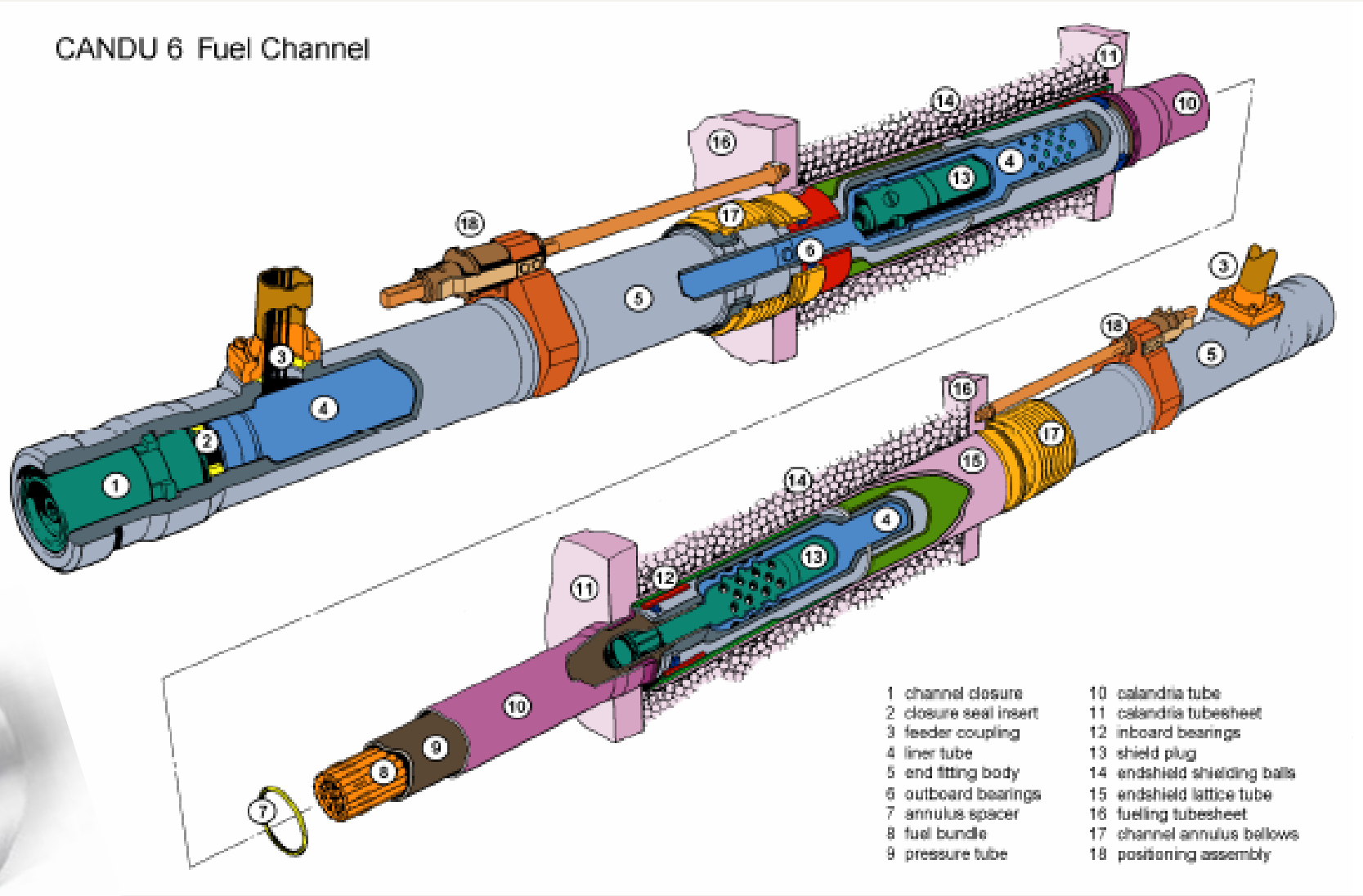
CANDU Reactor

CANDU Units operating
in Canada, South Korea, Argentina,
Romania, China, Pakistan, and India.



Pressure Tube

- Supports the fuel in the core
- Contains pressurized coolant and directs flow over fuel
- Permits unrestricted fuel passage



Life cycle of the CANDU nuclear reactor

- Design and Construction
- Operation
  - On-line fueling
  - In-service inspections performed as per CSA N285.4
- Refurbishment possible
  - Several major components including the pressure tubes are replaced
  - Operating life roughly doubled
- Shutdown and decommissioning

Licensing

Probabilistic evaluations of pressure tube

- In CANDU reactors the fuel is located within pressure tubes instead of a single pressure vessel
  - Pressure tubes are nominally 104 mm in diameter, 4.2 mm in wall thickness and approximately 6 m long
- During operation only a fraction of the pressure tubes are required to be inspected in-service
- FFS must be demonstrated for all pressure tubes, referred to as “the core”
- Probabilistic methods are permitted by CSA N285.8 when performing evaluations of the core
- CSA N285.8 permits both deterministic and probabilistic evaluation methodologies

Evaluations of pressure tube

- Pressure tube FFS evaluations for the core required by CSA N285.8:
  - Evaluation of protection against fracture
    - Evaluate service conditions for protection against pressure tube rupture due to an unknown severe flaw for all ASME Service Level loadings
  - Core assessment of pressure tube flaws and contact between pressure tube and calandria tube
    - Provide assessment of overall risk of pressure tube rupture in reactor core due to pressure tube flaws and contact between pressure tube and calandria tube
  - Evaluation of leak-before-break
    - Evaluate reactor unit's capability to shutdown and cooldown to prevent pressure tube rupture in the event of a leaking through-wall pressure tube flaw

Probabilistic evaluations of pressure tube

- Deterministic methods are successfully applied to satisfy CSA N285.8 requirements for pressure tube FFS evaluations in early to mid-life
- As the reactor ages and material properties begin to degrade, probabilistic methods become essential to satisfy CSA N285.8 requirements for FFS evaluations
- Probabilistic methods reduce conservative assumptions regarding:
  - Flaw severity
  - Bounding material properties
  - Transient occurrence
- Probabilistic methods provide quantification of the probability of failure
- OPG has successfully applied probabilistic methods in pressure tube FFS evaluations to achieve safe and reliable operation of CANDU reactors

Probabilistic evaluations of pressure tube

Probabilistic Evaluation	Computer Code	Development Began	Acceptance Criterion Basis	Acceptance Criterion in CSA N285.8
Fracture Protection (PFP)	SCEFPR	2014	Design Intent	Proposed for incorporation
Core assessment of flaws (PCA)	SCEPTR	2005	Safety Analysis Limits	Incorporated
Core assessment of PT/CT* contact (PBSA)	PROBE	2013	Safety Analysis Limits	Incorporated
Probabilistic Leak Before Break (LBB)	P-LBB	2013	Safety Analysis Limits	Incorporated

*Pressure tube to calandria tube contact. Probabilistic Blister Susceptibility Assessment (PBSA)

Probabilistic evaluations of pressure tube

- Pressure tube probabilistic evaluations, as currently performed, include uncertainty analysis at a baseline level
- When results of probabilistic FFS evaluations approach their associated acceptance criteria, CSA N285.8 requires an enhanced uncertainty analysis
- The enhanced uncertainty analysis employs a rigorous bottom-up approach to uncertainty characterization and propagation that is intended to improve confidence in evaluation results
- OPG has participated in pilot studies aimed at developing the methodology for enhanced uncertainty analysis

Enhanced Uncertainty Analysis

- CSA N285.8 includes guidance for performing enhanced uncertainty analysis in probabilistic evaluations
- Guidance is provided in a non-mandatory Annex. Enhanced uncertainty analysis is to be performed when outcome of probabilistic evaluation reaches a specified level with respect to relevant acceptance criterion
- More detailed information on the current work to incorporate enhanced uncertainty analysis into probabilistic FFS evaluations is provided in a separate presentation at this symposium

Summary

- OPG has a long history of safe and reliable operation of CANDU nuclear reactors
- Probabilistic methods are permitted by CSA N285.8 when evaluating pressure tube FFS
- OPG has participated in developing methodologies and computational tools for performing probabilistic FFS evaluations of CANDU pressure tubes
- OPG has successfully applied probabilistic methods when performing FFS evaluations of CANDU pressure tubes since 2007 to support mid-life to late-life operation
- OPG continues to support development of enhanced uncertainty analysis methods and tools for future use

ONTARIO POWER GENERATION

Electrifying life in one generation.

Thank you!